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EVALUATION OF THREE MINIATURE RADIO TRANSMITTER ATTACHMENT METHODS FOR SMALL PASSERINES

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Biologists have used radio telemetry to study wildlife since the 1960's (Lord et al. 1962, Cochran et al. 1967, Amlaner and MacDonald 1980, Cochran 1980, Kenward 1987), but most work has been with mammals and medium- to large-sized birds (>20 g) using radio transmitters weighing >2 g. Numerous harness ar-

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rangements and adhesives have been used with varying success to attach transmitters to birds (Godfrey 1970, Dunstan 1972, Fitzner and Fitzner 1977, Raim 1978, Perry et al. 1981, Knittle et al. 1985). These studies did not provide quantitative data on feather wear, tissue abrasion, physical condition of the birds, or behavior.

We needed data about the effects of attaching transmitters weighing 1 g or less to the back of small birds (<20 g) prior to radio-marking Kirtland's warblers (*Dendroica kirtlandii*). This endangered species breeds in Michigan and winters throughout the Bahama Archipelago (Mayfield 1960, 1975). Radio telemetry was required to determine factors limiting the size of the Kirtland's warbler population and to identify management strategies to effect its recovery. Prior to radio-marking Kirtland's warblers, we had to demonstrate that transmitters would not injure the birds, would not appreciably alter behavior or flying ability, and would fall free of the birds in a month or less. Thus, objectives of this study were to evaluate 3 transmitter attachment methods by documenting behavioral responses and flying ability, recording weight changes of the birds, determining the degree of feather wear and tissue abrasion, and estimating the number of days that a transmitter remained attached.

METHODS

This study was conducted from late September through November 1985 at the Patuxent Wildlife Research Center, Laurel, Maryland, in 8 outdoor parallel flight pens, each 3.0 m long, 1.1 m wide, and 2.3 m high. Each pen was joined to the side of a 1-story wooden building. A small shrub and 2 clumps of sedge provided some cover, and 2 bare branches afforded perches. The complex of 8 pens was covered around the perimeter with green nylon wind screen to provide a visual barrier and reduce exposure during stormy weather.

We centered a 23- × 34-cm window of 5-mm-thick plexiglass (covered with sunscreen film for 1-way viewing) 1 m above the floor in the wall of the building of each pen to provide observers with an unobstructed view without disturbing the birds. Each window had a clear plexiglass viewing port (8 × 12 cm) to enable observers to discriminate between colors of leg bands on birds. We built baffles of polyester screen, extending from the ground to the roof, into corners of each pen where it joined the building to eliminate observer blind spots.

The common yellowthroat (*Geothlypis trichas*) was chosen for this study because it was readily available. It is in the same subfamily (Parulinae) as the Kirtland's warbler, and, like the endangered bird, spends much of its time in low, dense vegetation and forages frequently on the ground (Bent 1953, Mayfield 1960). Although the yellowthroat is smaller ($\bar{x}$ weight of females = 9.9 g, range 7.6–15.3 g, n = 655; $\bar{x}$ of males = 10.3 g, range 7.6–15.5 g, n = 965; Clench and Leberman 1978) and is not a tail-bobbing species like the Kirtland's ($\bar{x}$ weight for both sexes = 13.8 g, range 12.3–16.0 g, n = 77; Mayfield 1960), we decided it was the best surrogate. Of the other 2 tail-bobbing species readily available, the prairie warbler (*Dendroica discolor*) was too small ($\bar{x}$ weight of females = 7.3 g, range 5.7–10.8 g, n = 110; $\bar{x}$ of males = 8.0 g, range 6.1–10.1 g, n = 149; Nolan 1978) and the palm warbler (*Dendroica palmarum*) too difficult to maintain in captivity in the numbers required for the study (R. S. Greenberg, Natl. Zool. Pk., pers. commun.). We used immatures (hatching year) because there is less mortality during acclimation to captivity than among adults (R. S. Greenberg, Natl. Zool. Pk., pers. commun.).

Handling of the birds was limited to 4 times in 60 days and human intrusion into and around the pens was kept to a minimum to reduce stress. Food and water were provided in excess in multiple containers spaced to prevent an individual bird in a pen from dominating these resources, strict pen sanitation was maintained, and medical problems were treated immediately. All birds remained wary of us throughout the study.

Fifty-three wild-caught birds were obtained from banding operations at Laurel, Maryland (n = 10 birds), Island Beach State Park, New Jersey (n = 16), and Kiptopeke Beach, Virginia (n = 27). Thirty-two birds were randomly selected for use in the experiment. Birds were fed and watered daily between 0700–0800 h.

Four birds were kept in each pen. Each bird was banded with 2 size No. 1 colored plastic, butt-end leg bands, 1 band per leg and 1 color per individual. We randomly selected a control and 3 test birds in each pen. Birds were permitted to acclimate to the pens for 29–34 days prior to attaching the transmitters. Three birds were randomly selected in each pen to receive 1 of the 3 attachment methods, and transmitters were attached the day before the experiments started. Behavior, flight, and transmitter retention experiments (8 controls and 24 tests) began on 26 October 1985. The first 2 experiments were completed in 20 days and the retention experiment in 30 days. The birds were observed in each pen for 20 minutes per day, and behaviors were recorded every 45 seconds by scan sampling (see Altmann 1974). Each pen was observed consecutively, in the same sequence, each day. The following behavior categories were used: flying; feeding and drinking; maintenance (preening, bathing, bill wiping, wing stretching, resting, pecking at the harness, pecking at the transmitter); hopping; and interacting with other bird(s) in pen.

We observed behavior from inside the building through the viewing windows. One person made observations and called out each behavior for each bird, and a second person entered data on a portable microcomputer (Hensler et al. 1986). After completing the daily behavior observations, we recorded the number of flights per bird for 20 minutes at each pen. Two observers recorded flights simultaneously, each watching 4 pens. We defined flight as flying 0.33 m or more from 1 perching position to another.

Birds were weighed with a 30-g capacity Pesola scale (to 0.5 g) after they were placed in the study pens, and at the start, midway, and end of the behavior and flight experiments. We recorded physical condition of each individual at the beginning, midway, and end of the study: (1) excellent—light or no feather wear, no skin abrasion, less than 15% weight loss, smooth feather appearance, and alert; (2) good—moderate feather wear and/or 15–20% weight loss, moderate to no skin abrasion, smooth feather appearance, and alert; (3) fair—heavy feather wear and/or >20% weight loss, large skin abrasion (3–5 mm), smooth feather appearance, and alert; and (4) poor—heavy feather wear and/or >20% weight loss, large skin abrasion (>5 mm), lesion extending under skin, ruffled feathers, and lack of alertness. Feather wear was categorized as: none, light (few feathers involved), moderate (many feathers involved), and heavy (most feathers involved around the areas of the harness and transmitter). Skin abrasion was categorized as: none, mildly erythemic, small (<1 mm), moderate (1–3 mm), large (>3 mm), and lesion involving underlying tissue. Postmortem examinations were conducted on all birds that died during the study.

Percent weight loss during the experiment and during the first and second halves of the experiment was analyzed using a randomized block analysis of variance (ANOVA) with attachment methods as treatments and pens as blocks. Scheffé's multicomparisons test was used to compare individual attachment methods (Steel and Torrie 1980). Another ANOVA, with sex and attachment methods as the 2 factors, tested for sex differences in percent weight loss. The number of flights and the proportion (arcsine transformed) of the time spent flying, feeding, maintaining, hopping, and interacting were analyzed separately as a split-plot ANOVA (Steel and Torrie 1980:395) with periods (26–31 Oct, 1–7 Nov, and 12–18 Nov) as the split-plots in time. Analyses were conducted using SAS procedure GLM with type IV sums of squares (SAS Inst. Inc. 1985).

Dummy transmitters (facsimiles of operational units) were 8 × 8 × 19 mm, with 9-cm whip antennas. The mean weight of the 24 dummy transmitters was 1.09 g. This represented 8.6% of the weight of the average yellowthroat used in the study, and was 8.0% of the Kirtland's weight. The 3 transmitter attachment methods (henceforth methods) were: eyelash adhesive of quick-drying, non-irritating latex base used with chiffon fabric (adhesive method), the adhesive with velcro (velcro method), and the adhesive with a combination of chiffon and a harness (harness method). The adhesive method was a modification of that developed by Raim (1978) for brown-headed cowbirds (*Molothrus ater*). The adhesive method consisted of a single layer of white chiffon fabric attached to the underside of the transmitter at each end with surgical suture or cotton sewing thread. One thread was whipped through the chiffon at each end of the transmitter. A drop of cyanoacrylate was placed on all knots. The chiffon was trimmed to the general shape of the outer perimeter of the transmitter.

For the velcro method, mated pieces of velcro were cut to the shape of the outside perimeter of the transmitter. The top piece of 2 mated pieces of velcro was secured to the underside of the transmitter with cyanoacrylate and the bottom piece mounted on the back of the bird. The harness method consisted of a single layer of chiffon attached to the underside of the transmitter (adhesive method). A pre-tied neck loop (15-mm diameter) of thread was glued (cyanoacrylate) to the anterior of the transmitter. A thread 10 cm long was tied and glued to the midpoint of the neck loop. A thread 15 cm long was then glued at its midpoint to the posterior of the transmitter to form an abdominal loop.

To attach a transmitter, we held the bird firmly in 1 hand and pushed forward the spinal tract feathers in the interscapular region. A patch of feathers slightly larger and about the same general shape of the transmitter was then clipped at the skin surface. The chiffon on the underside of the transmitter was coated with lash adhesive. The use of excess adhesive was avoided to prevent soiling the feathers around the clipped area. Feathers were held away from the clipped area and transmitter (antenna extending posteriorly) placed along the axis of the spine. The transmitter was held in place 3–6 minutes to permit the adhesive to dry. We used similar procedures with velcro. For the harness, we first clipped the back feathers, slipped the bird's head through the neck loop, applied the adhesive to the chiffon, then held it in place to dry. Strands at the rear of the transmitter were then adjusted and tied across the abdominal region. The abdominal connector was adjusted from the neck loop for fit and tied to the midpoint of the abdominal loop. We trimmed excess thread, taking care to avoid making the harness adjustments too tight and hence restricting movements of the bird.

We held birds with transmitters still attached at the completion of behavior and flight experiments up to 30 days from the time the transmitters were attached to check retention capabilities of the 3 methods.

RESULTS

Behavior

Three behaviors were significantly different between treatments (Table 1): pecking har-

Table 1. Percent of time spent by captive common yellowthroats in behaviors that differed significantly ($P <$ 0.05) between 3 transmitter attachment methods (treatments).[a]

		Treatments (%)			
Activity	P	Control (1)	Harness (2)	Velcro (3)	Adhesive (4)
Pecks harness	0.0005	0.0A[b]	1.0B	0.0A	0.0A
Pecks transmitter	0.0007	0.0A	0.2A	2.4B	0.4AC
Preens	0.0399	2.3A	7.2B	5.9B	4.4AB

[a] Split-plot analysis of variance was used with the pen × treatment effect serving as the error term for treatments.
[b] Means within a row followed by different letters are different ($P < 0.05$; Tukey's multiple comparison test).

ness, pecking transmitter, and preening. Birds with the velcro attachment spent significantly more time pecking at transmitters. Time preening was significantly different between controls and harnessed birds and between controls and birds with the velcro. There were also significant differences between periods for 6 behaviors (Table 2). The percent time flying, pecking harness or transmitter, and hopping decreased over the course of the study. The percent time feeding was highest for the second period (1–7 Nov), and the percent time resting was highest in the third period (12–18 Nov). Significant interaction between treatment and period ($P = 0.004$) was observed for pecking harness; decreasing from period 1 to period 2 (2.9 to 0.2%) and not observed in period 3. Sample sizes for behaviors bathing, bill wiping, and wing stretching were too small to warrant analysis.

Table 2. Comparison of percent of time spent in behaviors by captive common yellowthroats between observation periods.[a]

		Periods (%)[b]		
Activity	P	1	2	3
Feeds	0.0196	17.8A[c]	22.0B	13.7C
Flies	0.0161	1.4A	1.0AB	0.3B
Pecks harness	0.0049	0.8A	0.1B	0.0B
Pecks transmitter	0.0065	1.2A	0.5B	0.0B
Rests	0.0001	64.1A	60.1A	75.0B
Hops	0.0026	10.5A	10.1A	7.1B

[a] Split-plot analysis of variance was used with the pen × treatment effect serving as the error term for treatments.
[b] Period 1: 26–31 Oct; period 2: 1–7 Nov; and period 3: 12–18 Nov.
[c] Means within a row followed by different letters are different ($P < 0.05$; Tukey's multiple comparison test).

Flying Ability

There were no significant differences ($P > 0.05$) in the number of flights ($n = 479$) among experimentals or between controls and experimentals. The number of flights differed significantly ($P < 0.01$) among periods; period 1 had 135 flights, period 2 had 167 flights, and period 3 had 149 flights.

Physical Condition

During their entire period in captivity (21 Sept–18 Nov), the common yellowthroats used in this study showed a net weight gain; males had a mean gain of 15.6% (SD = 7.3), and females a mean gain of 11.2% (SD = 9.1). However, mean weights during the experiments (25 Oct–18 Nov) showed a net loss, males 8.0% (SD = 8.3) and females 10.3% (SD = 7.7). Initial mean weight for males was 10.3 g (n = 17, SD = 1.1) and females 9.7 g (n = 15, SD = 1.2).

No effect of sex on percentage weight loss was detected ($P > 0.05$). There was no significant difference ($P = 0.33$) between weights of control and test birds at the beginning of the behavior and flight experiments. Only harnessed birds exhibited significantly greater weight loss over the course of the experiments than controls ($P < 0.05$). This effect occurred in the first half of the experiment. No weight loss differences were significant during the second half.

Three warblers died during the study from enteritis (9.4%), an adhesive group male (captivity stress) and 2 harness group females (coccidiosis). The general physical condition of the remaining birds was excellent throughout the study. No feather wear was observed on any of the birds. We detected moderate-size skin abrasions on 3 harness group birds midway through the study, but all survived the experiment. These abrasions apparently were caused by the knot of the abdominal cross connector of the harness and had healed and were not visible on final examination.

After a transmitter fell off a bird, the skin of the interscapular region was covered by overlying contour feathers from the dorsal tract. The adhesive generally adhered to the chiffon fabric and pulled the calami and basal portion of the feather rachi from the feather follicles where the transmitter had been mounted. The backs of the test birds (n = 24) had no sign of erythema or abrasions. Removal of the feather bases appeared to stimulate feather replacement in the affected follicles. New feathers (n = 4 birds) emerged within 2–4 days after the transmitters fell off, and the area was fully covered with feathers up to 25 mm in length in 17–24 days. Emergence of new feathers was delayed until the adhesive came off. The replacement of feathers on the back was independent of the molt cycle.

Transmitter Retention

Median retention times were 24 days for the adhesive method and 13 days for the velcro. The differences between these methods were not significant ($P > 0.05$). With the adhesive, 43% (SE = 19%) of the transmitters fell off before 15 days (the expected life of the batteries) and 43% (SE = 19%) of them were retained after 30 days. With the velcro, these percentages were 38% (SE = 17%) and 12% (SE = 12%), respectively. No harnesses (n = 6) fell free within the 30 days.

The transmitters gradually loosened from the skin, usually starting anteriorly and laterally. Loosening was probably hastened by pecking, preening, bathing, and scraping against objects. All birds bathed regularly 1 or more times per day followed by intensive preening and ruffling of the feathers. This activity could lead to gradual loosening of the transmitter.

Transmitters

Our experimental attachments of miniature transmitters to the backs of common yellowthroats caused no short-term problems under captive conditions. There were no obvious differences in behavior and flying ability among the 3 attachment methods and the controls (Table 3).

DISCUSSION

We determined the adhesive was the preferred transmitter attachment method and the harness the least desirable for warblers. Although velcro has many good features, it has too high a profile and adds more weight than the other 2 methods. With velcro the back feathers do not cover the transmitter, probably increasing air resistance in flight (Obrecht et al. 1988). The harnesses did not detach within 30 days, caused significantly greater weight loss, and were extremely difficult to attach to the back of a small passerine. The adhesive method had the largest number of desirable characteristics (Table 3).

Transmitters should be thin (top to bottom) and smoothly contoured (streamlined) on all surfaces. A thin unit (i.e., adhesive) was more easily covered by feathers, was probably more readily accepted by the bird, and rode in a better position (low profile), hence would be aerodynamically superior (see Obrecht et al. 1988) to thicker units (i.e., velcro). The underside of the transmitter should be slightly concave along the long axis to conform to the back of a small bird. This also is important to facilitate a good adhesive seal between the skin and the chiffon. Some dummy transmitters of

Table 3. Comparison of 3 transmitter attachment methods used on captive common yellowthroats, October–November 1985.

Characteristics	Attachment method		
	Adhesive	Velcro	Harness
Low profile on back	Yes	No	Yes
Complete unit of minimum size	Yes	No	Yes
Complete unit of minimum weight	Yes	No	Yes
Easy to attach	Yes	Yes	No
Fall off in 30 days or less	Yes	Yes	No
Birds tend to become entangled in apparatus	No	No	Yes
May tend to be stressful	No	Yes	Yes
Back feathers preened to cover transmitter	Yes	No	Yes
Can cause erythema or abrasions	No	No	Yes
Restrict flying ability	No	No	No
Modify behavior	No	No	No
Make feeding and maintenance activities difficult	No	No	No
Significantly greater weight loss than controls	No	No	Yes

irregular underside shape made bonding difficult.

The flexible property of the rubber-based adhesive in combination with the flexibility of the chiffon fabric apparently permits enough resilience to form and retain a good bond with the surface of the skin during movements by the bird. Repeated attempts to attach transmitters using the adhesive directly on the underside of the unit without the chiffon layer did not work; the transmitter fell off in 3 days or less, generally within a matter of hours. The single layer of chiffon fabric should have rounded corners so that there are no "points" for the bird to grasp and consequently cause premature loosening of the seal between fabric and skin.

When centered on the upper back, the transmitter is close to the center of gravity, is less likely to create a problem with balance, and is more difficult for a bird to peck. Generally, the birds immediately preened the feathers to cover the transmitter. The unit in this position seems to ride well for nonbreeding activities (we did not examine predator avoidance, however).

The amount of adhesive should be minimized so it will pull free when the transmitter falls off, and thus not delay growth of new feathers. Excess adhesive will cement adjacent feathers together, which then must be cut and removed. Unnecessary feather removal exposes bare skin to the environment and could cause a thermo-regulatory problem for the bird.

The fact that the transmitter rode higher on the back with the velcro attachment method may explain the greater amount of pecking by these birds. Birds with harness and velcro preened significantly more than controls, indicating that these 2 attachment methods were more stressful. There were no significant differences in amount of preening between controls and birds with adhesive attachments. Harnessed birds were observed pecking their harnessess, but this behavior decreased as the birds became acclimated. Transmitter pecking also decreased over time indicating possible acclimation.

Feeding, flying, resting, and hopping varied with period, and it is thought to be related to migratory condition of the birds. The greater number of flights during period 2 might reflect the birds' natural physiological condition during fall migration.

Common yellowthroats used in the study were obtained during the course of their extended fall migration. Hence, the weight changes we observed over course of the study may have been related to the physiological condition of the birds during their migratory period.

Subsequent to this study, radio transmitters attached with the adhesive method to wild Kirtland's warblers ($n = 5$; 1 adult [after hatching year] and 4 immatures [hatching year]) in Michigan in August 1986 were retained from 3 to 9.5 days ($\bar{x} = 6.2$, SD = 2.52) (P. W. Sykes, Jr. and D. A. Jett, unpubl. data). This was 33% less retention time than with the yellowthroats in our study. Therefore, the adhesive method was modified in 1987. Skin bond cement (natural rubbers, 1.1.1.-trichloroethane) was used instead of eyelash adhesive. Wild Kirtland's warblers ($n = 7$; 2 adults and 5 immatures) were radioed in Michigan during July and August. The skin bond cement kept the units in place for 3 to 25 days ($\bar{x} = 9.86$, SD = 7.27) (P. W. Sykes, Jr., D. A. Jett, and C. B. Kepler, unpubl. data). Skin bond cement was superior to lash adhesive for transmitter attachment because it held longer, dried more quickly, and was easier to use. However, latex-base adhesives might not work on species that have strong bills. R. T. Sugihara (U.S. Fish and Wildl. Serv., Hawaii Natl. Pk., pers. commun.) found this to be the case with introduced northern cardinals (*Cardinalis cardinalis*) on the island of Hawaii.

Our experience suggests several factors may affect retention of adhesive-secured transmitters on small passerines: (1) quality and size of area of the seal between the skin and adhesive, (2) tolerance of individual birds to the transmitter unit, (3) position of the transmitter on the back, (4) state of molt at time the transmitter was attached, and (5) periods of rainy weather. The longer retention using lash adhesive on captive common yellowthroats might be due to behavioral differences in the 2 species, restriction of spatial movement, or other artifacts of captivity, and smaller bill size of the captive birds. Higher moisture conditions during early morning might have decreased retention on the wild birds. Our results suggest that 1-g transmitters could be used on Kirtland's warblers.

SUMMARY

There were no significant differences between the 3 treatments (attachment methods) and controls when considered day by day or period by period for flying, feeding, hopping, and interacting behaviors nor in the number of flights among experimentals and controls or among experimentals. There were significant differences in preening, pecking transmitters, and pecking harnesses among the treatments. There were significant differences between periods for flying, feeding, pecking harness, pecking transmitter, resting, and hopping. Range of retention for transmitters was highly variable for adhesive (2–24 days) and velcro (1–25 days) methods, and no transmitters of the harness method fell free within the 30-day test period. The general physical condition of 90.6% of the birds was excellent for the 30-day period of the study; 3 individuals were lost to enteritis. New feathers emerged in the interscapular region within 2–4 days after the transmitter fell off, and the area was fully feathered in 17–24 days. Feather replacement in such cases was independent of the molt cycle.

We believe the adhesive method of transmitter attachment to small birds is the preferred technique when it incorporates several characteristics: (1) thin (top to bottom) with smooth contour on all surfaces, (2) underside slightly concaved to conform to the back of a small bird, (3) single layer of chiffon fabric attached with thread to each end of the transmitter underside, (4) chiffon fabric trimmed with rounded corners to conform to the shape of the transmitter, and (5) latex-base adhesive used to attach transmitter to back of bird.

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